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EFFECT OF METAL BACK CONTACTS ON TETRAHEDRAL AMORPHOUS CARBON FILMS GROWN USING THE CATHODIC ARC PROCESS.

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ABSTRACT

Reported here is a study on the effect of different metal back contacts on the electrical and structural properties of the tetrahedral amorphous carbon (ta-C). The films were grown using a pulsed cathodic arc system. Ta-C films were deposited simultaneously on silicon substrate, precoated with the following metals, namely aluminium (Al), gold (Au), chromium(Cr), molybdenum (Mo), copper (Cu), tungsten (W) and titanium(Ti). The electrical measurements and Raman response show that the back contact does influence the properties of ta-C films. These results are analysed with respect to our earlier report regarding the influence of back contacts on field emission from similar ta-C films.

INTRODUCTION

Tetrahedral amorphous carbon (ta-C) is being studied with great interest for use in diverse areas including electronics, vacuum microelectronics, sensors, MEMS and tribology.[1-4] The ta-C films have been grown using a wide variety of processes including, Filtered cathodic vacuum arc(FCVA) - direct and pulse source, Pulsed laser ablation deposition (PLAD), Mass selected ion beam(MSIB) deposition and Electron cyclotron wave resonance (ECWR) process. The interest in ta-C films, stems from the possibility of tailoring the material properties, varying from highly diamond-like (sp^3)[1-5] to highly graphite-like (sp^2)[6] materials including fullerenes[7] and nanotubes[8] by varying the growth conditions. Further in general, most of these processes are room temperature process, allowing for the use of low cost substrates like glass.

Considering the amount of ta-C work reported in literature, and the increased importance of ta-C films and carbon films in general, it is surprising to note that there are very few reports on the effect of metal back contacts, on the properties of the ta-C films. Especially with the enhanced interest in carbon based materials for use as field assisted electron emitters[9-15] we believe there is an urgent need for study on the effect of back contacts. In the case of field emitters, the main factors that could influence emission are the barrier or interface at the back, the transport of carrier through the film and the nature of the front surface. Among the three factors mentioned above, the aspect that has been less reported is the effect of back contacts on field emission. One of the first report on the effect of back contacts on field emission from ta-C films was by Hart et.al[16]. They had reported that the emission threshold field did not show any consistent trend or dependence on the back contacts. The threshold field was defined as the field

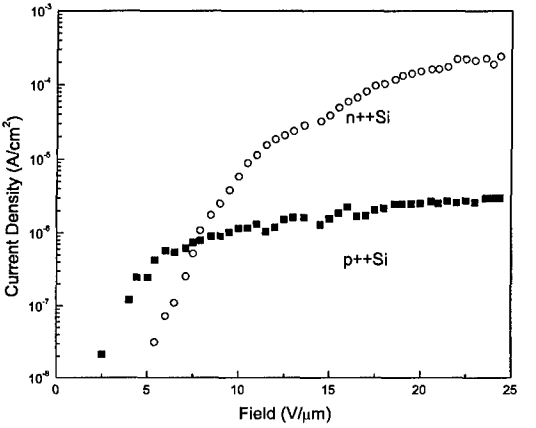

Figure 1. Field emission current density Vs applied field plot for ta-C films deposited on n++ and p++ Si substrates.

at which an emission current density of 1 $\mu A/cm^2$ was obtained [9]. However at lower current densities Satyanarayan[17] had shown that the back contact did have an influence on the emission current at a given field. Shown in figure 1 is the field emission characteristics of a highly sp^3 bonded ta-C films grown on p++ and n++ silicon substrates. It can be seen from the figure that the onset of emission is at quite low fields in the case of p++ Si substrate as compared to the n++ Si substrate. Though at the defined threshold of 1 $\mu A/cm^2$, the fields are nearly similar. Lower field emission from ta-C films deposited on P - type silicon substrates has also been reported by Cheah et.al[18]. Recently Rupesinghe et.al[19] reported observing difference in emission current at lower fields. Using *in situ* x-ray photoelectron spectroscopy and optical spectroscopy Rupesinghe et.al[19] measured the valence and conduction band offsets for ta-C films grown on *p* and *n* type Si. From the band measurements they showed the existence of a barrier and thus confirming the difference in the emission currents at the lower fields in the case of figure1. Suggesting a possible influence of the back interface on field emission from ta-C films. Also Arena et.al [20] have reported observing nanoclusters of carbon in the case of ta-C films grown on aluminium. While the ta-C films grown under identical conditions on silicon substrates were atomically smooth. Thus further indicating some dependence of the material property on the nature of the substrate or metal back contacts.

The cathodic arc process used for material growth, in all the work discussed above, is an highly energetic process. The film growth is believed to occur from the sub-surface, through a process of sub-implantation of the ions. Thus leading to a highly stressed films depending on the growth conditions[1-6]. The energetic ions during the process of sub-implantation may interact differently with the substrate, depending on the nature of substrate material or the metal back contact. Hence the study on the effect of back contacts is very essential. We report in this paper a study on the use of tungsten, titanium, aluminium, chromium, copper, gold, and molybdenum as back contact materials for the growth of ta-C films. Reported here is the

electrical and structural properties of the ta-C films grown on substrates with different metal back contacts. Raman spectroscopy was used to study the structural properties and Rutherford Back Scattering was used to estimate the possible effects at the interface.

EXPERIMENTAL CONDITIONS

First the metals for study as back contacts were deposited on to cleaned silicon substrates. The metals titanium, aluminium, chromium, copper and gold were deposited using thermal evaporation process in a vacuum of 10^{-6} torr. The metals tungsten and molybdenum were sputter coated on to the silicon substrate. Prior to deposition, the metal surfaces were cleaned in an argon plasma to remove any possible oxide layer. Then to eliminate the run to run variations in film quality all the substrates were coated simultaneously in a pulsed cathodic arc system at a substrate bias of 80V. The energy of the deposited ion is defined by the substrate bias.[1-4]The thickness of the ta-C films grown were nearly 50 nm. Next the films were prepared for the electrical measurements. The electrical measurements were made using a sandwich configuration consisting of "back metal contact/ta-C film/top metal contact". The top contact consisted of a two layer coating of nearly 30nm of gold and 60nm aluminium, deposited by a thermal evaporation process. The measuring area of the device was defined by using a contact mask with circular holes of 250 micron diameter. The electrical measurements (I- V) were carried out using Keithley multimeter with an in-built power source. The Raman measurements were carried out using a 515nm excitation, in a Renishaw micro Raman Spectrometer .

RESULT AND DISCUSSION

Shown in figure 2 are the forward and reverse, current - voltage characteristics of some of the ta-C films deposited simultaneously on different back contact metal substrates. It can be seen from the figure that there is not much difference between the forward and reverse currents. The contacts seem to be ohmic in nature. However the measured currents are different. Shown in figure 3 is the variation of the measured forward current at 0.5 V applied voltage with the work function of the various back contact metals used as substrate.

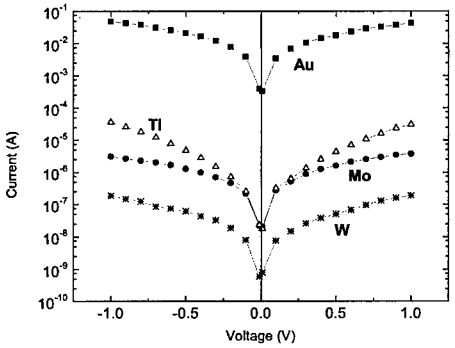

Figure 2 Current –Voltage plots of tetrahedral amorphous carbon (ta-C)

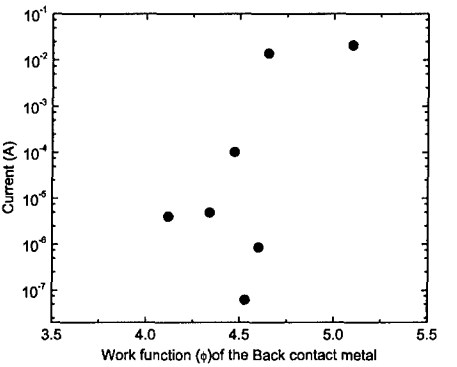

Figure 3 Variation of the measured forward current (at 0.5 V applied voltage) of ta-C films, with the work function of the metals used as back contact on the substrate.

Figure 3 shows that even though the ta-C films were deposited simultaneously on to substrates with different metals as back contact, the measured currents are not the same. However there seems to be no direct co-relation between the measured forward current at a given voltage and the work function of the back contact metal. But the figures 2 and 3 suggest that the properties of ta-C films, even if deposited simultaneously are influenced by the back contact metal or the substrate material. The variation in the current, could be due to numerous factors including possible oxide layer on the contact, inter-mixing of the carbon and metal atoms at the interface, different thermal gradients during depositions on different metal surfaces, change in stress during growth on different substrates and change in sp^2/sp^3 bonding ratio of the ta-C films. Thus in an effort to further understand the possible influence of the back contact metal on the material properties of ta-C films, Raman measurements were carried out. The Raman response and the peaks have been shown to be a good indicator of the structure and composition of the carbon based films [21,22 and references there in].

The Raman measurements on the ta-C films deposited on various back contact metal substrates show that the films are amorphous in nature. Shown in figure 4 is the possible relation between the work function of the back contact metal and the Raman G_{peak} position. From the figure it is difficult to discern a trend or relation. However the fact that the G_{peak} position has shifted with change in the back contact metal shows that the composition of the material is influenced. Ferrari et.al in their elegant three stage model[21] for the interpretation of the Raman spectra in the case of carbon films, suggest that the G_{peak} position may either increase or decrease with change in sp^3 bonding, depending on the percentage of sp^3 bonds. The G_{peak} position is more influenced by the sp^2 phases. Further it does not depend on the stress in the case of as grown ta-C films. J.K.Shin et.al[22] have reported that the G_{peak} position is shifted due to the stress in ta-C films. In the present experiment, the ta-C films were deposited simultaneously on all the back contact metal substrates. Yet, irrespective of whether the influence is due to clustering or stress, a shift in the Raman G_{peak} was observed. Thus showing that the film property is influenced by the substrate or the back contact metal.

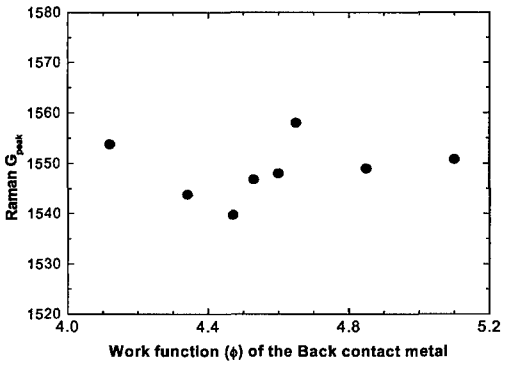

Figure 4 Shift in the Raman G_{peak} of ta-C films with the Work function (ϕ) of the back contact metal.

Further Rutherford Back Scattering experiments were carried out to study the effect at interfaces between the back contact metal and carbon film. The measurements show that in some cases the inter-mixing of the metal and carbon atoms could be up to 20nm. A detailed report on this will be presented else were. Recently Koserev et.al[23] have reported the effect of back contact on field emission from carbon films grown using very high frequency chemical vapour deposition at low temperature. They observed that there is no direct correlation between the contact metal work function and the emission current. However the back contact roughness had a substantial effect on the emission threshold field. Thus indicating that the back contacts could influence the film properties. Hence with increased use of carbon and nanostructured carbons films grown using energetic ion assisted low temperature or room temperature processes in diverse application, there is a need for more detailed study of the influence of back contacts.

CONCLUSION

We have carried out a study on the effect of different back contact metals on the electrical and structural properties of the tetrahedral amorphous carbon (ta-C). We find that even though the carbon films were deposited simultaneously on to different substrates,

(i) There is a difference in the measured current for a given voltage or field,
(ii) All the devices show ohmic behaviour
(iii) The Raman G_{peak} seems to shift for ta-C films deposited on different substrates or back contacts metals, indicating a change in the film composition or sp^2/sp^3 bonding ratio.
(iv) However there seems to be no direct relation to the work function of the material.
(v) RBS measurements show that the inter-mixing of the metal and carbon atoms could be upto 20nm.

Thus the study shows that even when there is no direct relation, choosing a back contact for carbon has to be done carefully. When using energetic ion assisted processes, even if the process is same, depending on the back contact metal, the properties of the films may vary. The back contact may be chosen based on the film growth process, film thickness requirement and application.

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